Ocean Processes and Climate Change

(with an emphasis on the biologically relevant)

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Outline

Processes and Observations
- Physical state
  - Warming, Circulation, Sea level
- Chemical state
  - Acidification, Hypoxia

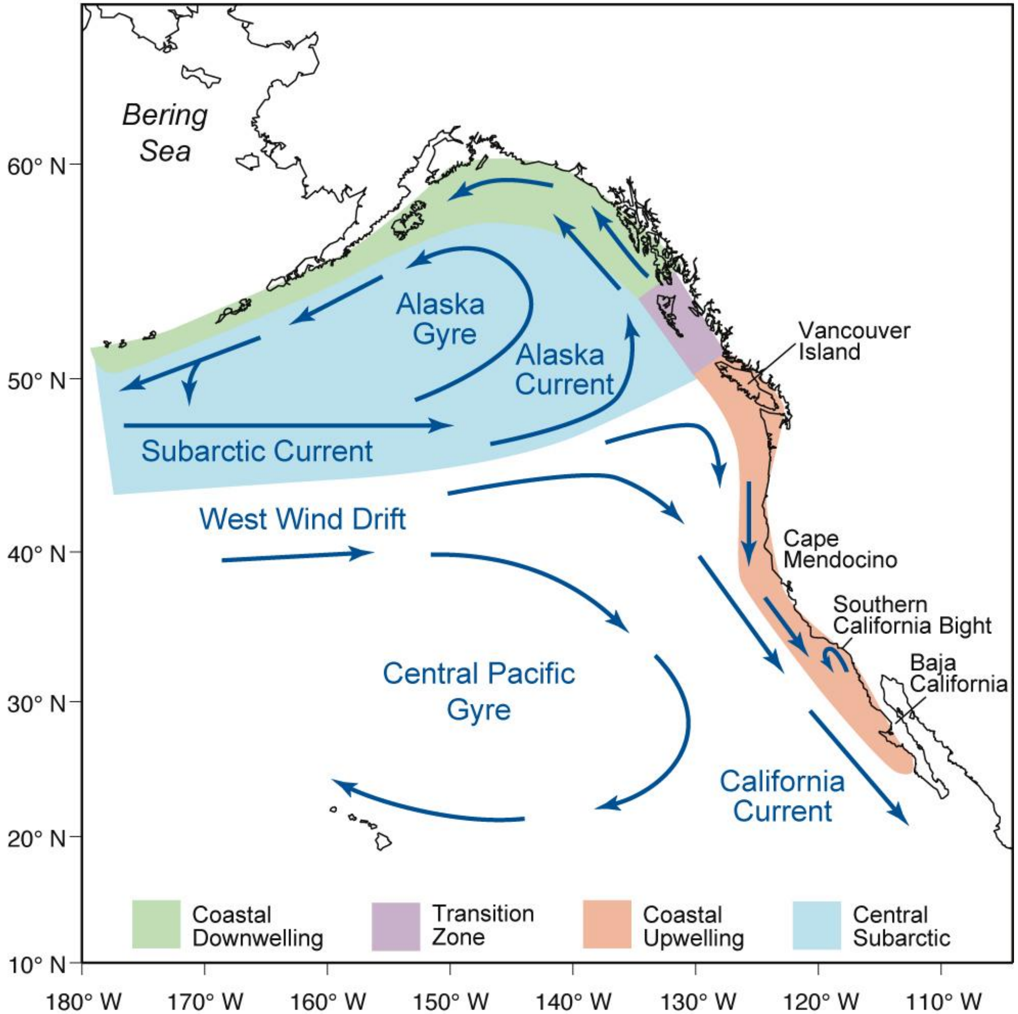
Current Research
- Biogeochemistry

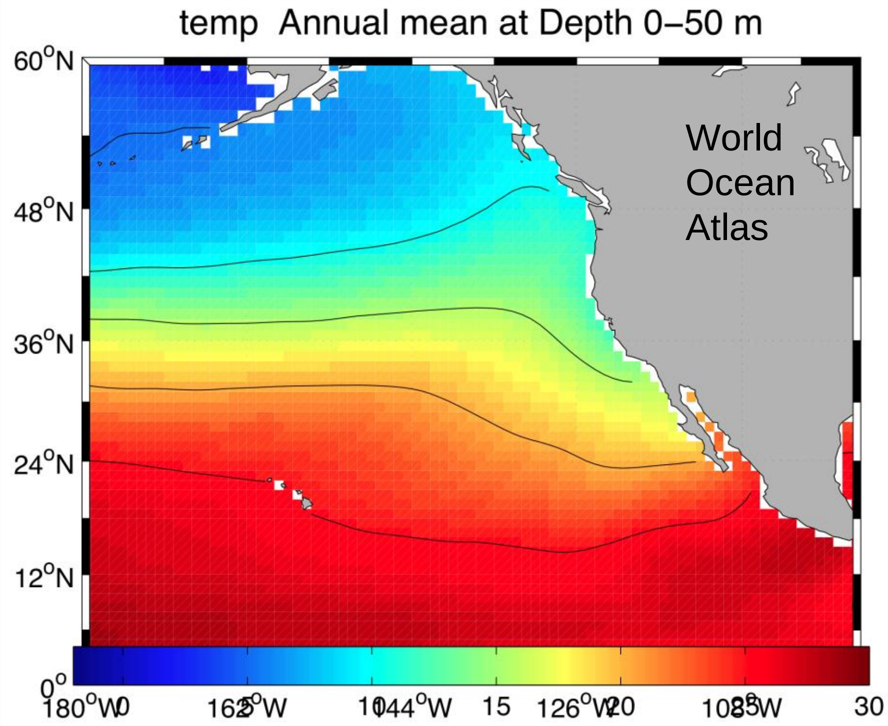
References

The oceanic environment of the East Pacific

- The coastal ocean off western North America is the eastern branch of large gyre circulations extending across the Pacific.
- The prevailing winds drive offshore flow, lowering the height and temperature of the sea surface, causing upwelling of deep water along the shore and energetic fields of eddies.
- This makes the California Current System ecosystem extremely productive.
- Productivity has a cost – the upwelling waters are low in oxygen and relatively acidic, poised near biological thresholds.

Gyre Circulations

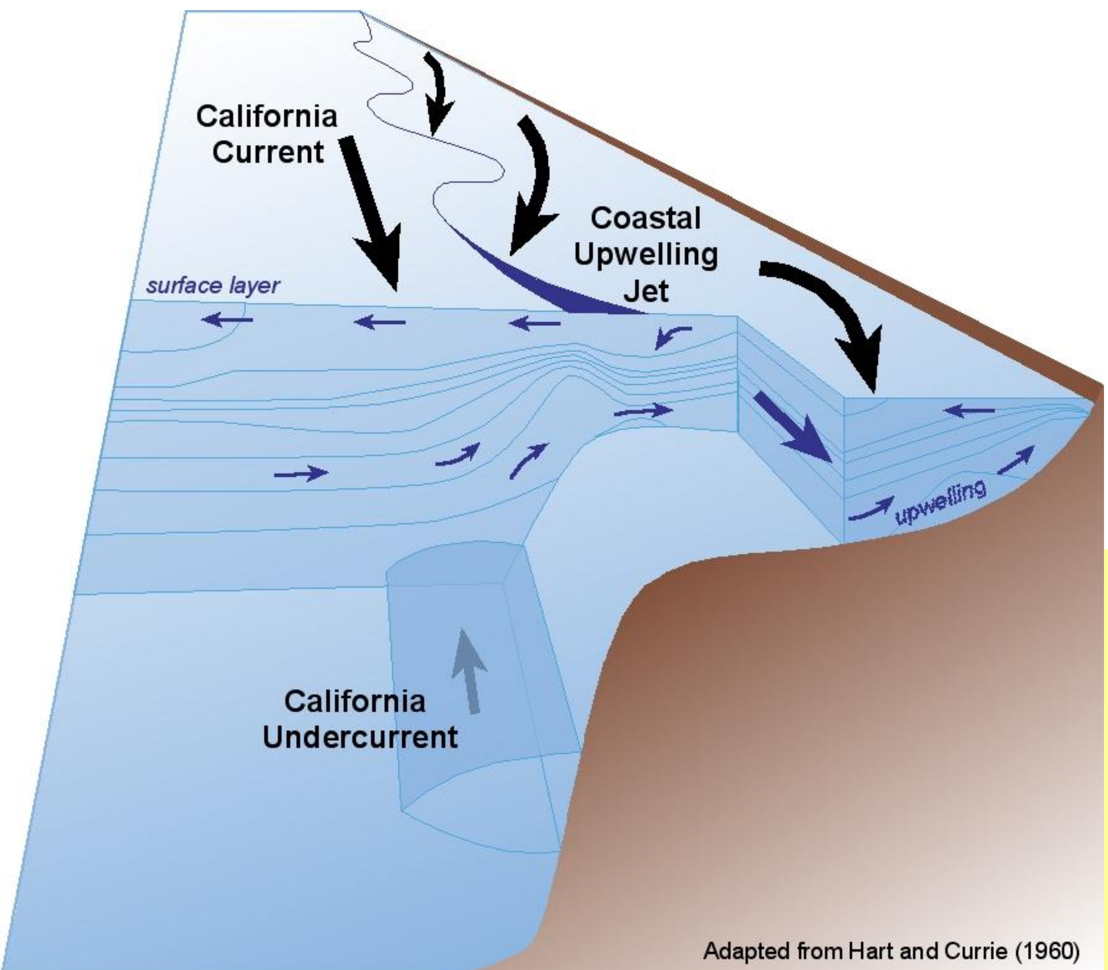




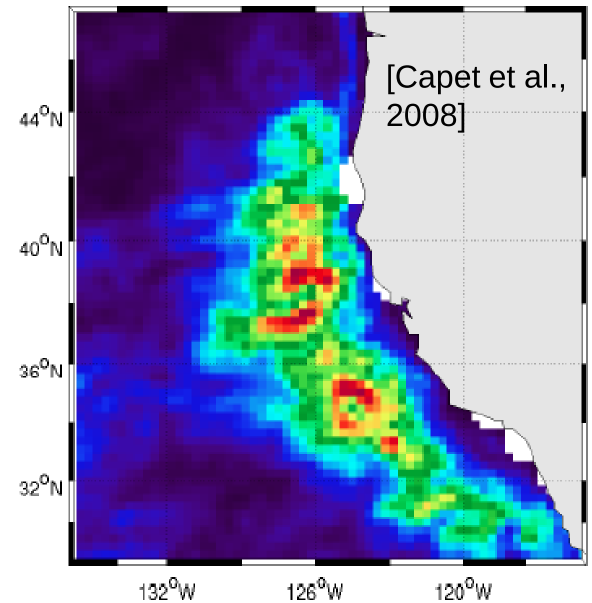
Surface currents organized into counter-rotating basin-scale “gyres”, with shared eastward current dividing N-S at North America. Contributes to relatively cold water along US west coast, and a weak latitudinal temperature gradient!

Coastal Circulation

Mean flow (schematic)

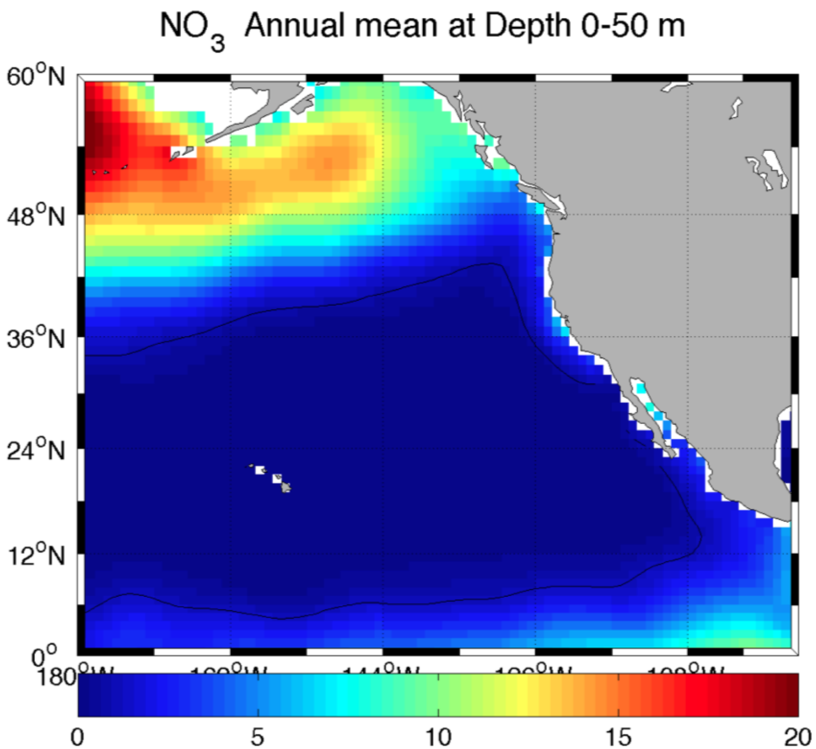


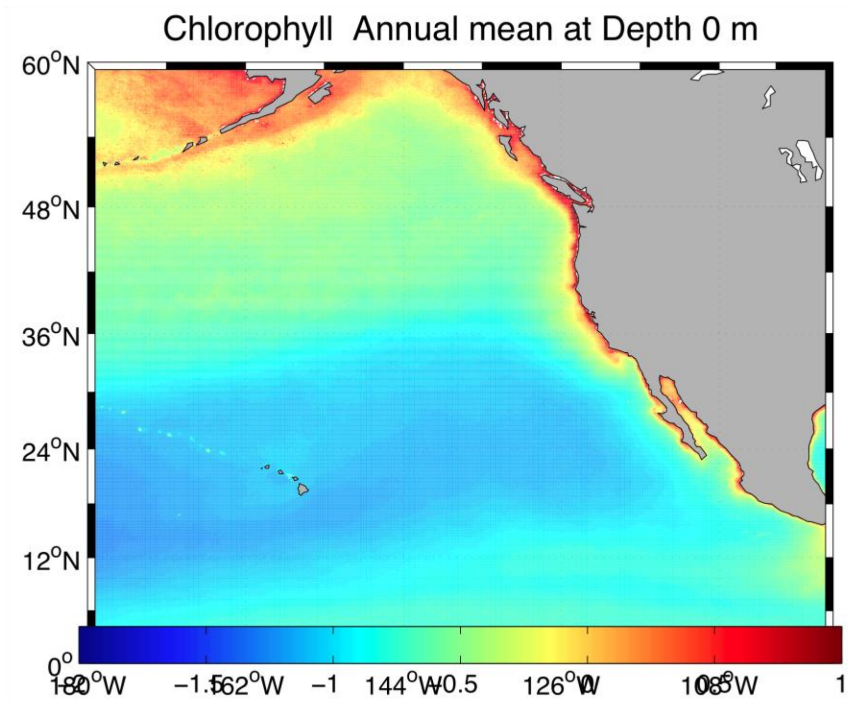
Eddy energy (satellite)



Offshore flow at the coast lowers sea level by ~10cm and lifts deep/cold/dense water toward the surface (upwelling). The sloping density surfaces sustain the mean currents and lots of transient eddies.

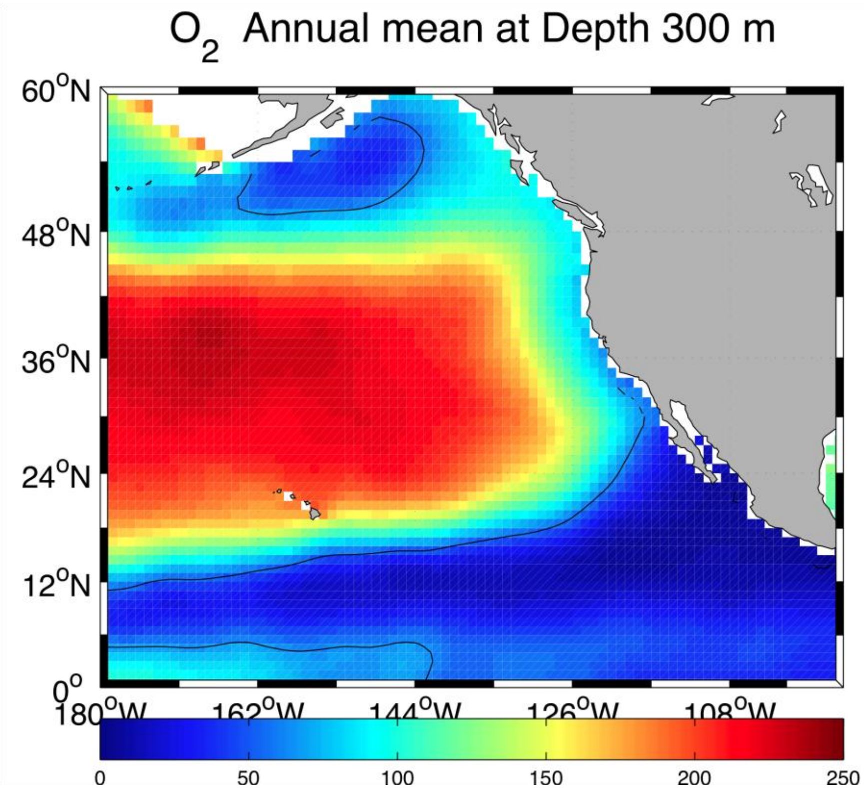
Biological productivity

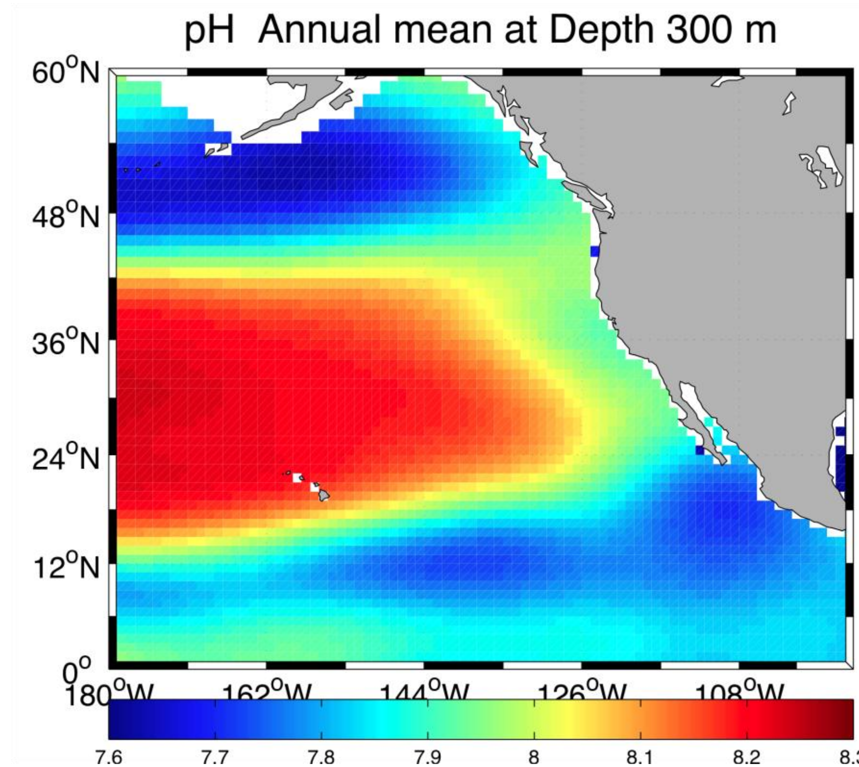




The upwelling of deeper water brings nutrients to the surface photic zone (left) that fuel the productive California Current ecosystem seen from satellite as band of high chlorophyll (right).

Ocean pH and O_2





Aerobic respiration

$$C_{106}H_{175}O_{42}N_{16}P + 150\ O_2$$

$$\downarrow$$

$$106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 78\ H_2O$$

CO_2 chemistry

$CO_2 + H_2O$ □ $H^+ + HCO_3^-$

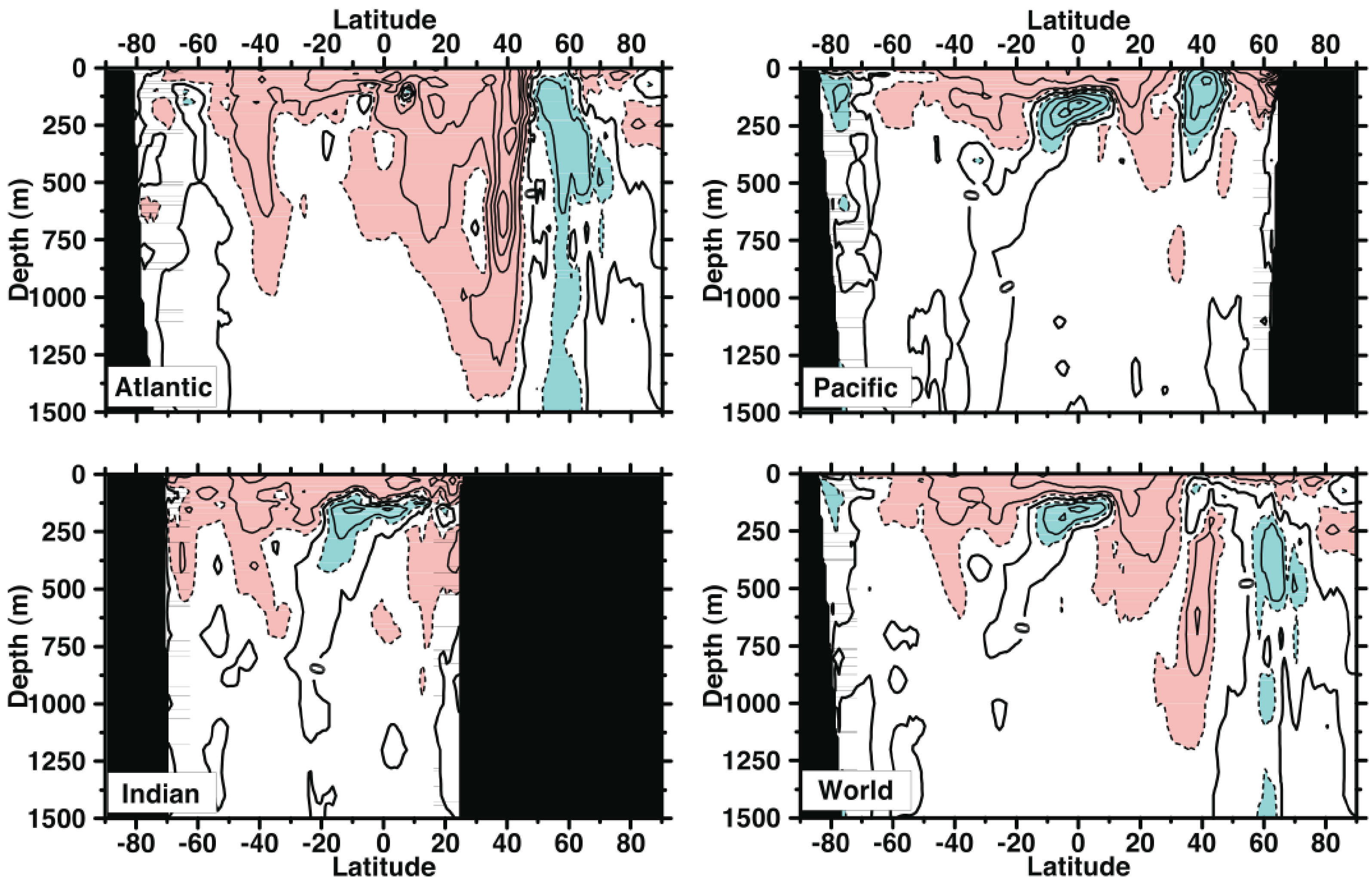
□ $2H^+ + CO_3^{2-}$

High productivity has biological costs – depletion of O_2 and lowering of CO_3 (and pH)

Climate Change in the East Pacific

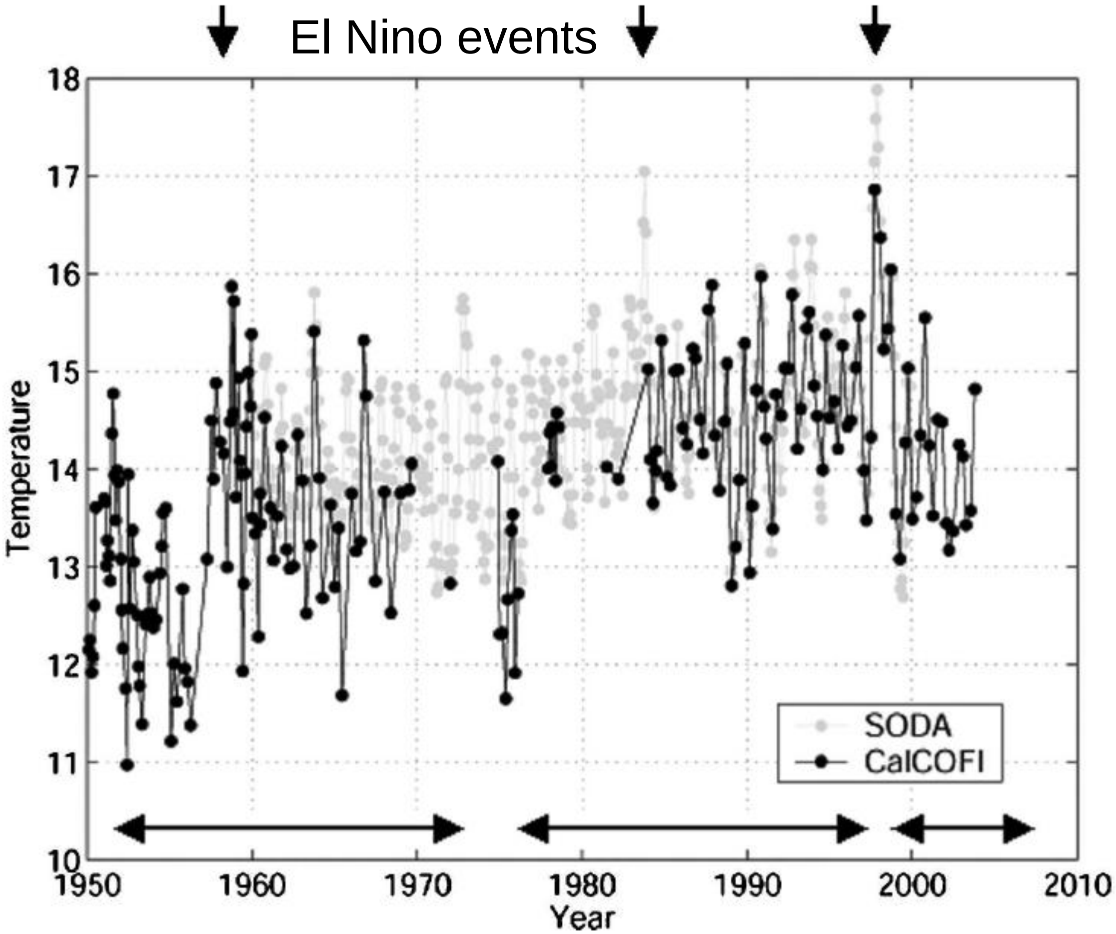
- Oceans are warming from the top down.
- Sea level rise (thermal expansion of sea water and melting of land ice).
- Decrease in surface density relative to deeper waters, increases the stratification and inhibits vertical exchange, with consequences for nutrient supply and oxygenation.
- Oceans are absorbing anthropogenic CO_2 from the atmosphere, making the oceans more acidic.

Ocean Warming



Linear trend (1955–2003) of zonally averaged temperature (contour interval 0.05°C per decade). The oceans are generally warming and stratifying.

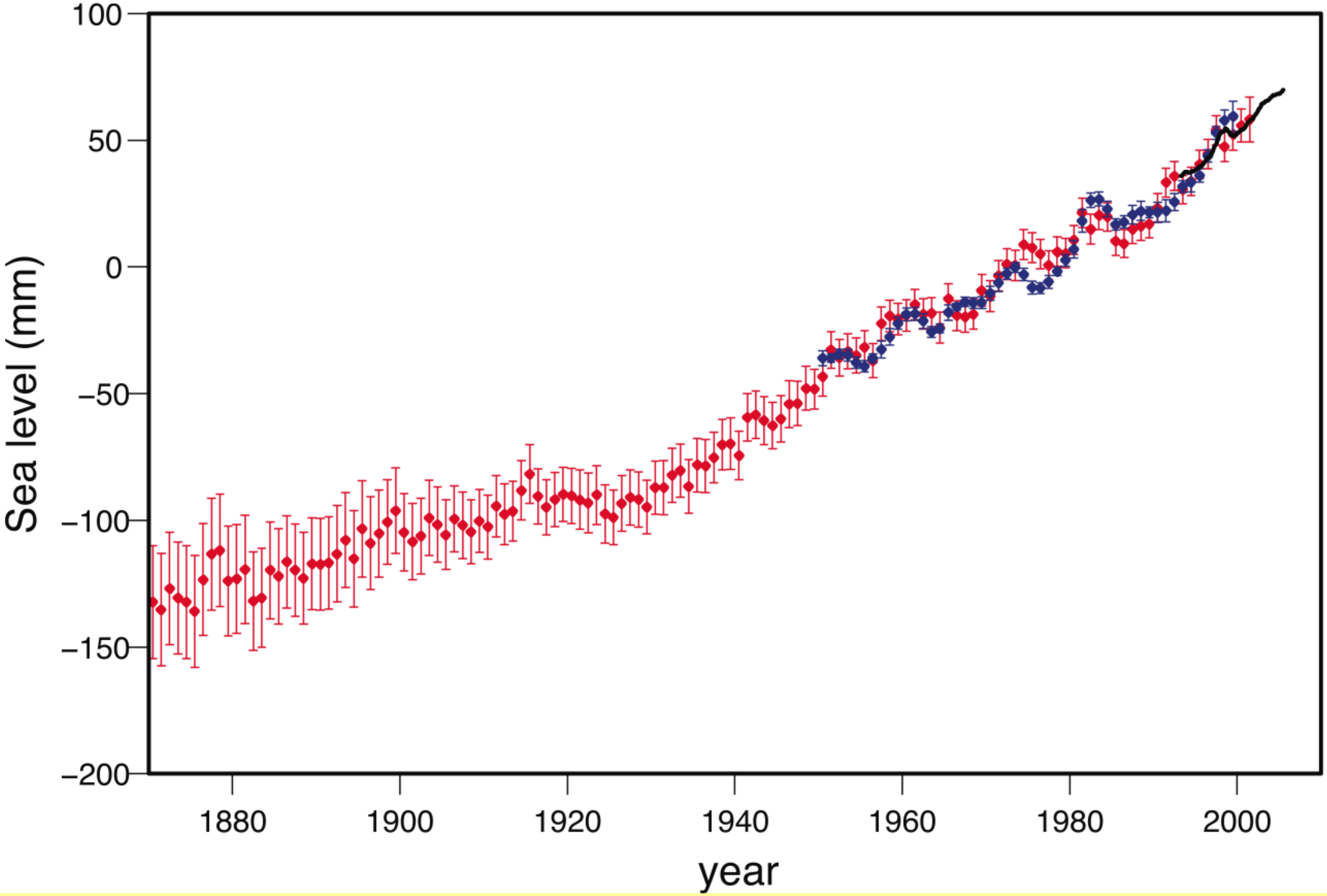
Warming in California Current



Kim and Miller [2007]

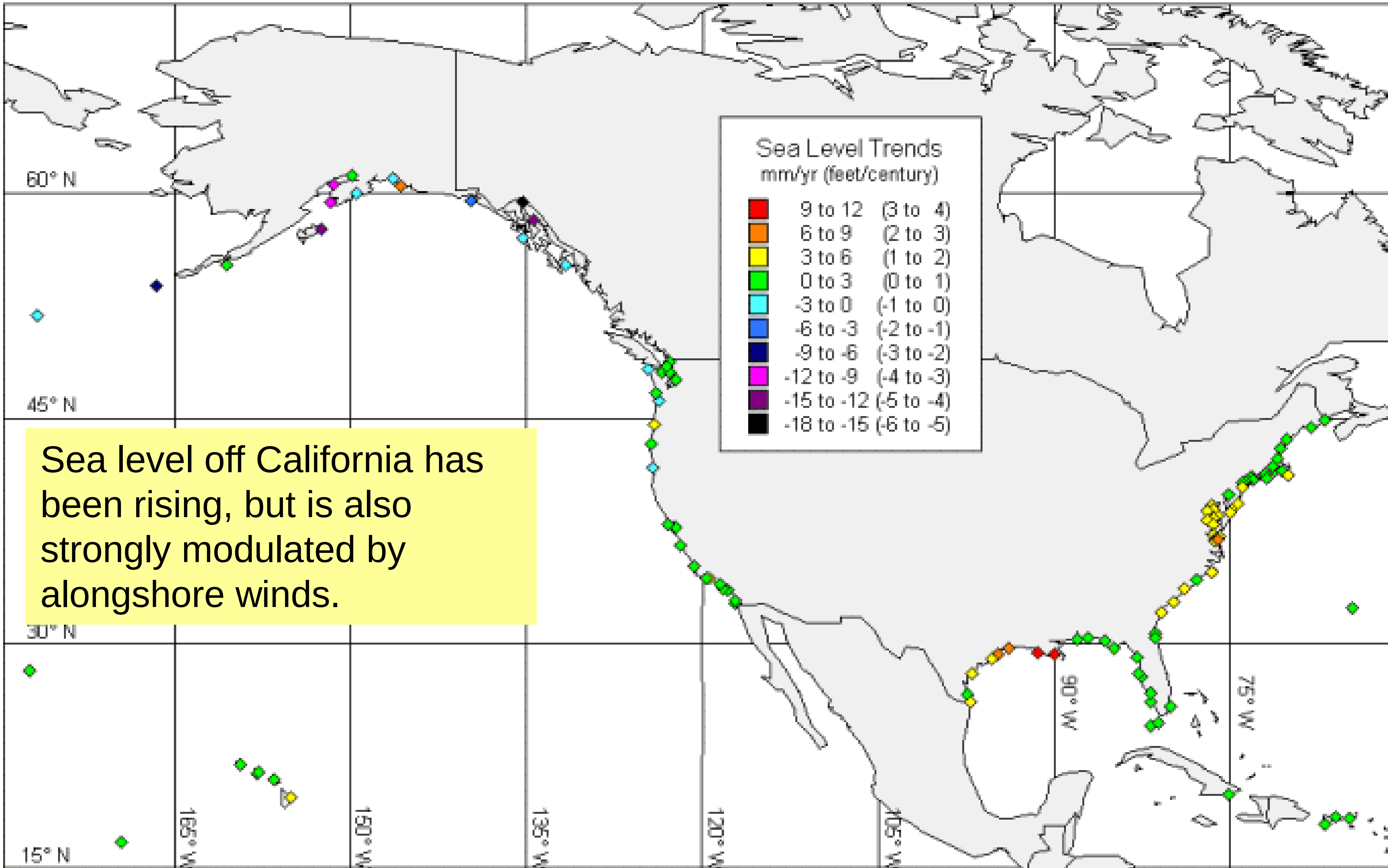
Long-term warming is observed in Southern California surface waters, although it is not evident in recent decades due to natural decadal variability.

Sea Level Rise



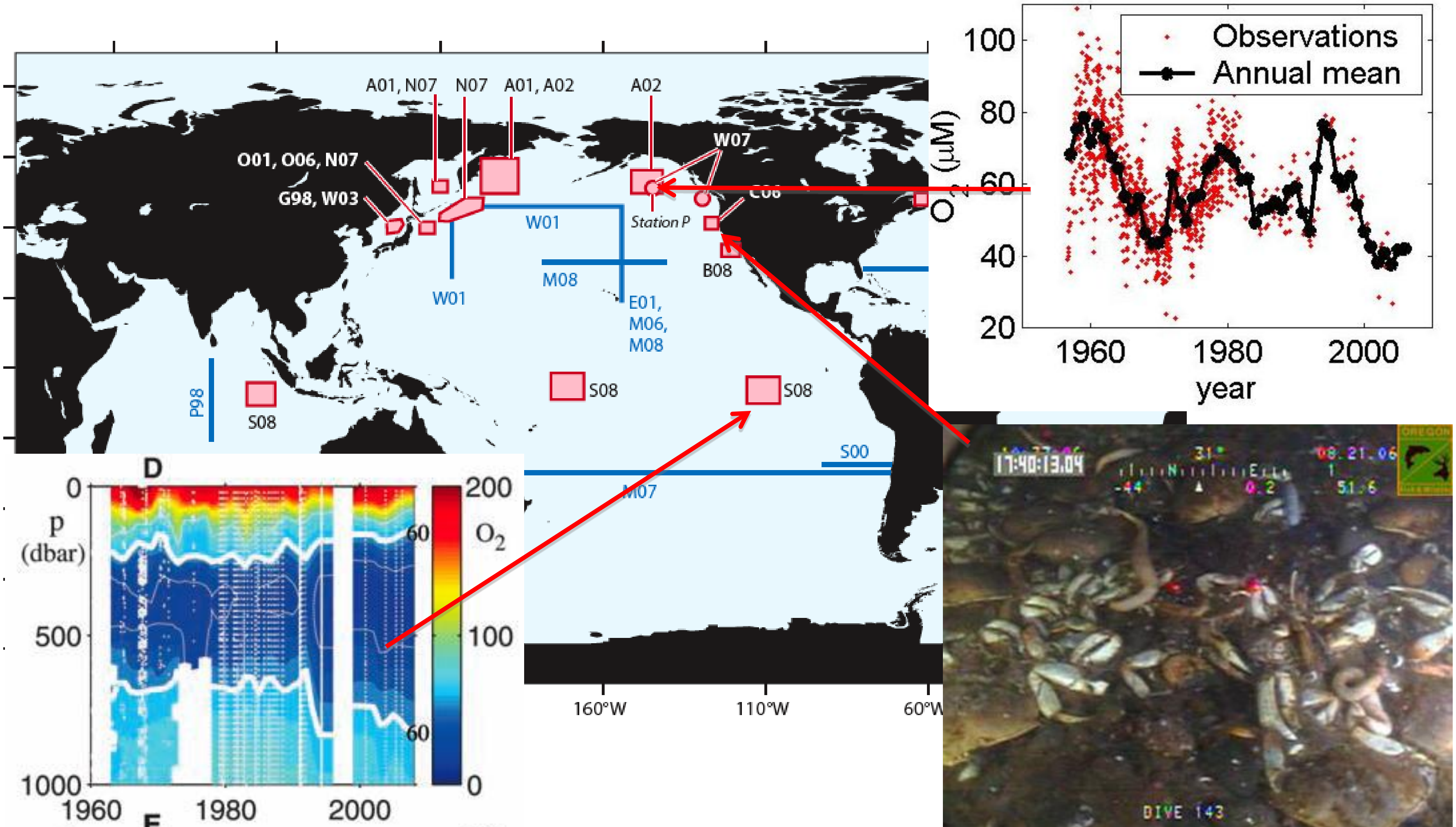
Annual averages of the global mean sea level (mm). A sea level rise of ~20cm to date, due to thermal expansion and melting land ice, is expected to accelerate (0.5-1 m by 2100).

Sea Level Rise: U.S.

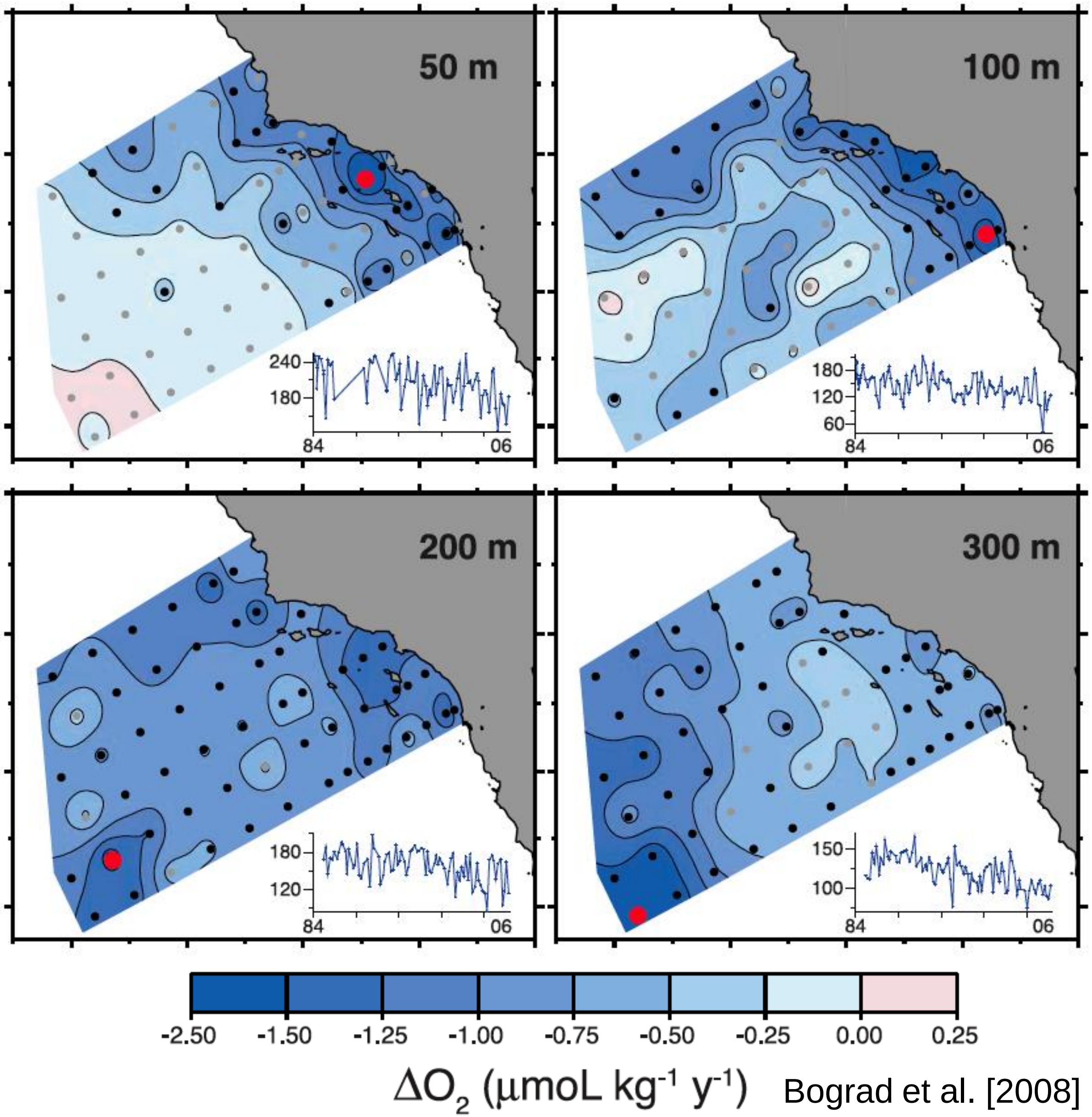


Sea level off California has been rising, but is also strongly modulated by alongshore winds.

Ocean Deoxygenation?



Oxygen in California Current



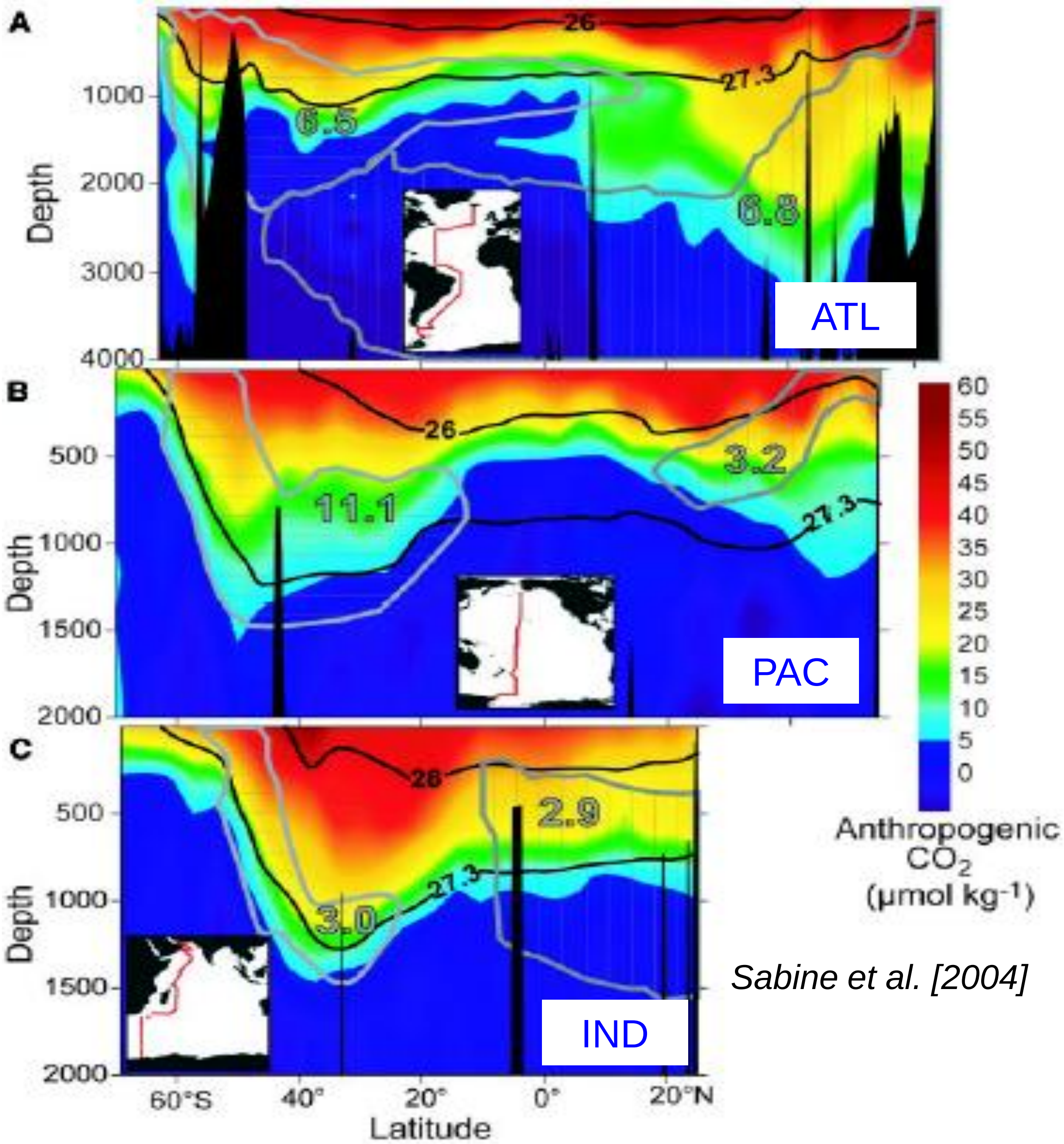
Bograd et al. [2008]

Oxygen concentrations appear to have declined since the mid-1980's.

1)Warming -> solubility

2)Stratification -> O_2 supply

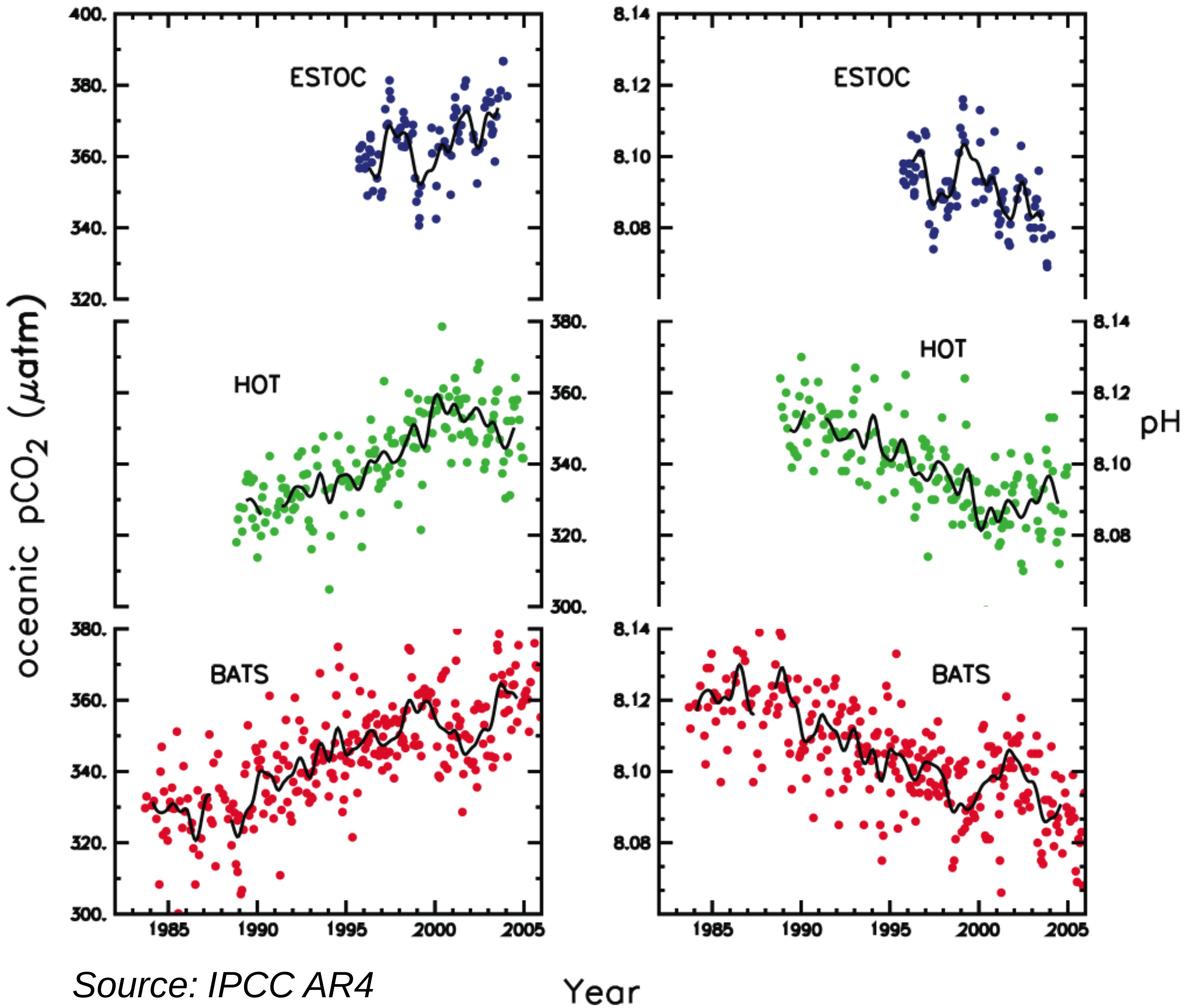
Ocean CO_2 uptake



Sabine et al. [2004]

The oceanic concentration of CO_2 attributed to absorption of anthropogenic CO_2 from the atmosphere. The oceanic uptake of CO_2 is a chemical/physical process governed by the rates and pathways of upper ocean circulation. The total uptake is estimated (for mid-1990's) to be ~120 billion tonnes of C, or about half the fossil fuel release.

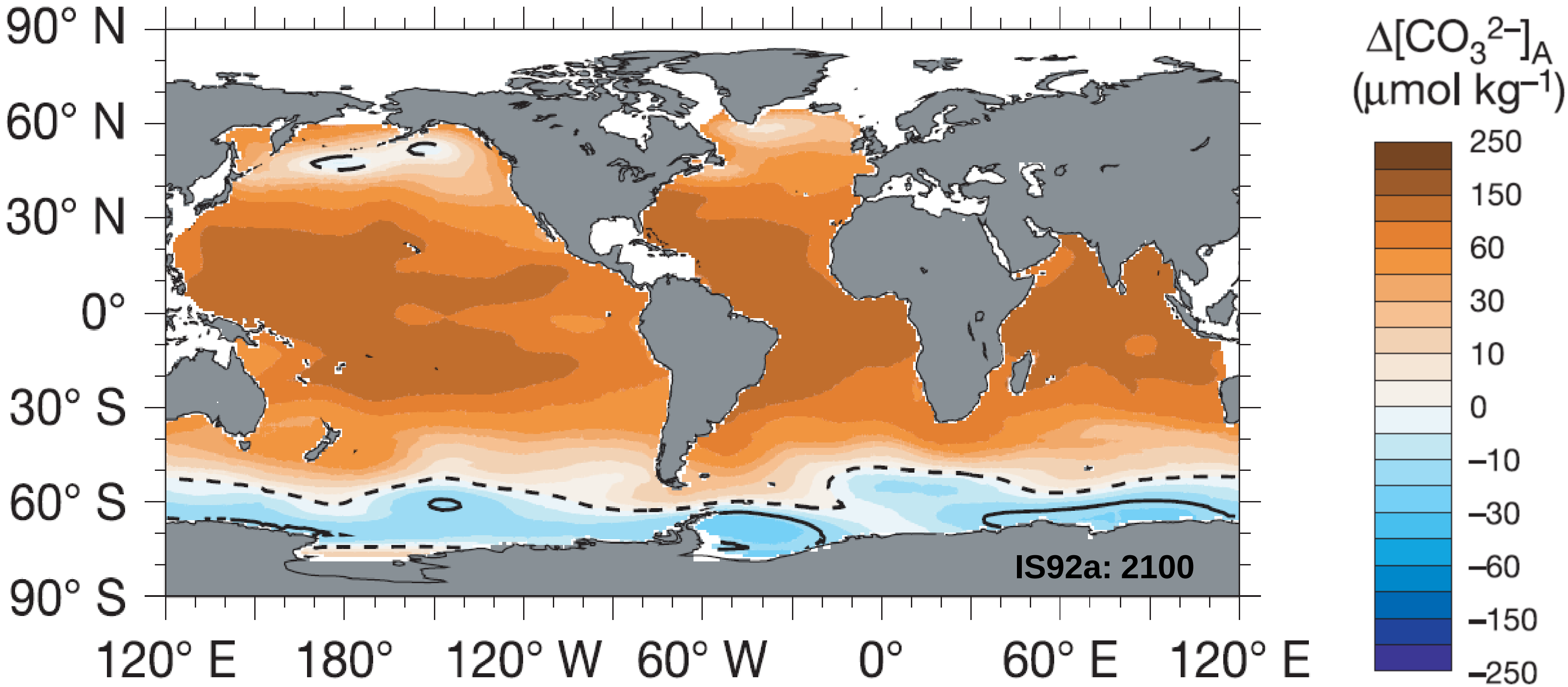
Ocean acidification



Source: IPCC AR4

Measured surface pCO_2 (left) and pH (right) at time-series sites in the Eastern North Atlantic Central North Pacific, Western North Atlantic. The most obvious direct consequence of increasing CO_2 is the reduction of pH.

$CaCO_3$ Undersaturation

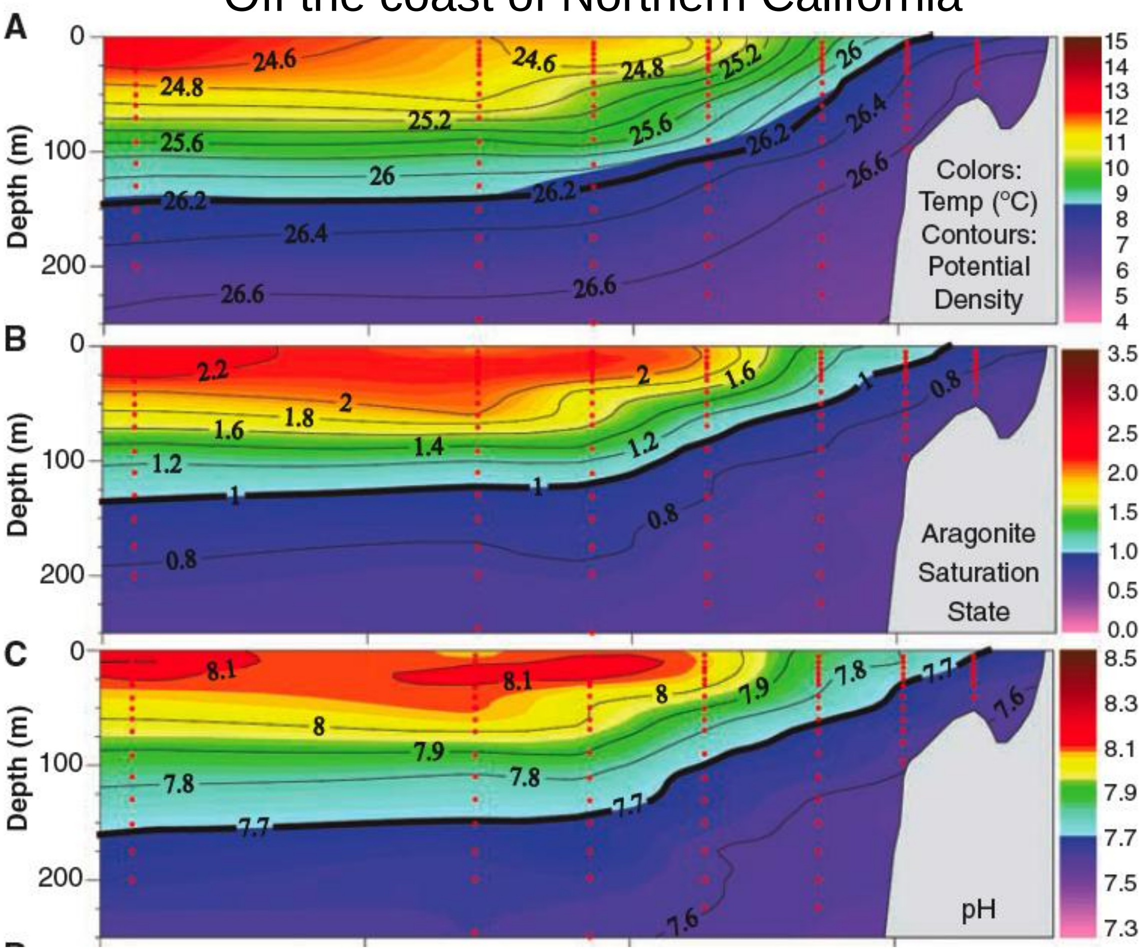


Orr et al. [2005]

The second direct consequence of increasing CO_2 is the reduction of $[CO_3^{2-}]$. This will cause the saturation state of $CaCO_3$ to decrease, leading to undersaturation in some environments within this century.

Coastal Upwelling Zones

Off the coast of Northern California



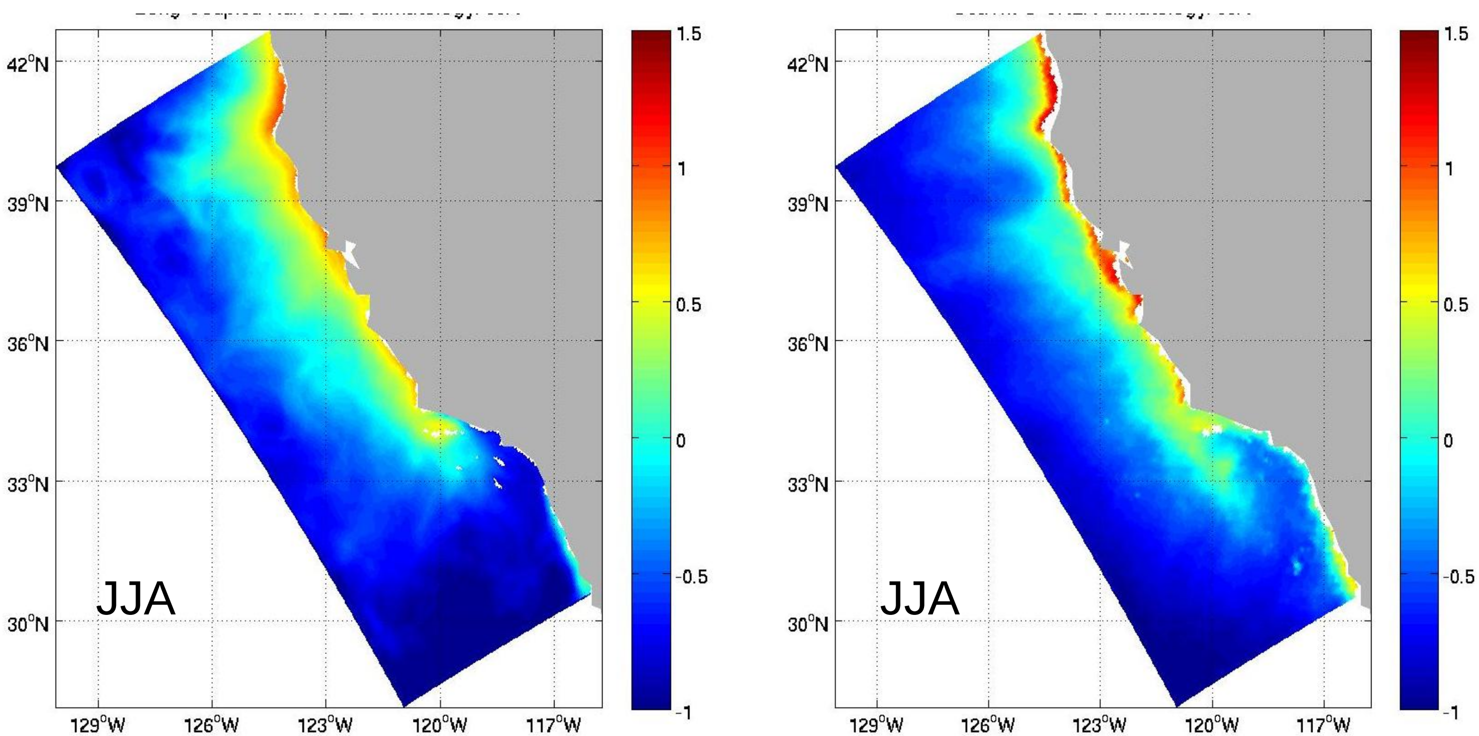
Feely et al. [2008]

$CaCO_3$ (aragonite) undersaturation has been directly observed and 0.2 of it attributed to anthropogenic CO_2.

Coastal upwelling regions may be particularly vulnerable to acidification because the upwelled waters are deep enough to have a low pH and $[CO_3^{2-}]$ but shallow enough to be receiving substantial anthropogenic CO_2.

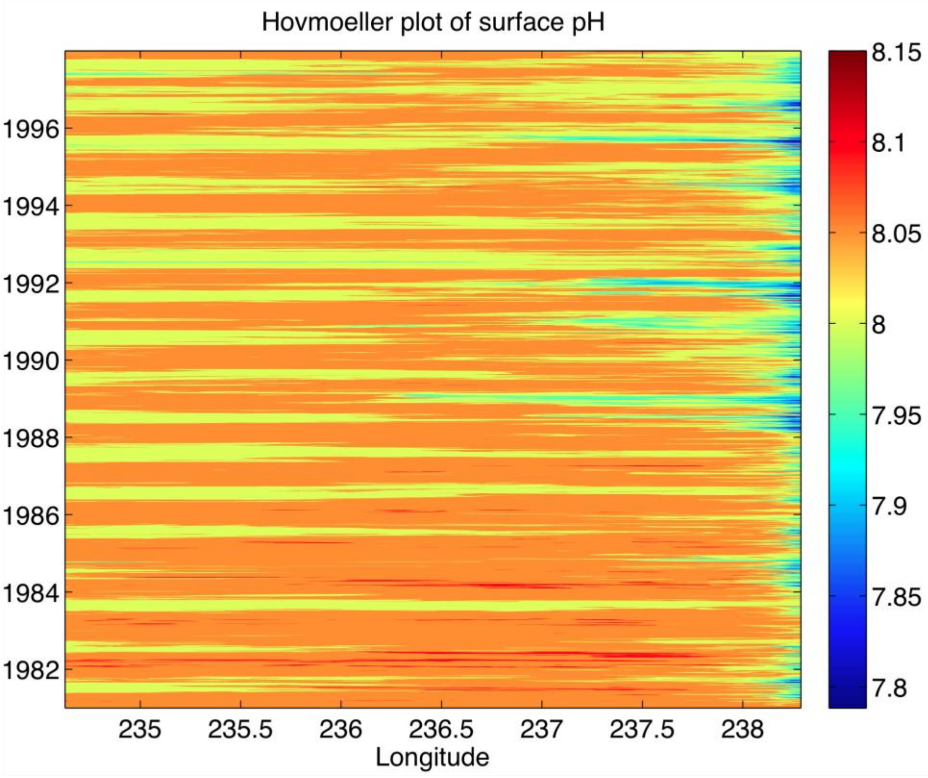
Marine Ecosystem/Carbon Cycle Model

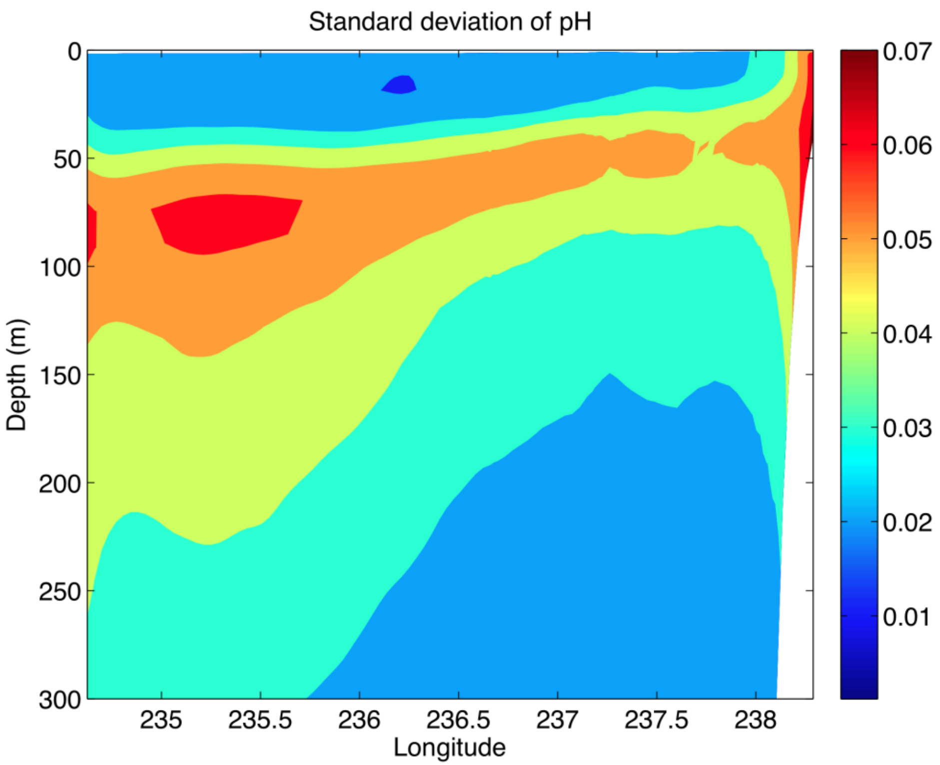
Simulated   Observed (SeaWiFS)



Summer chlorophyll (log scale) observed from satellite and simulated with the UCLA Regional Earth system Model. The model drives simple plankton ecosystem dynamics through self-consistent light, temperature and nutrient fields, and these in turn predict fluxes of carbon and oxygen.

Variability of pH

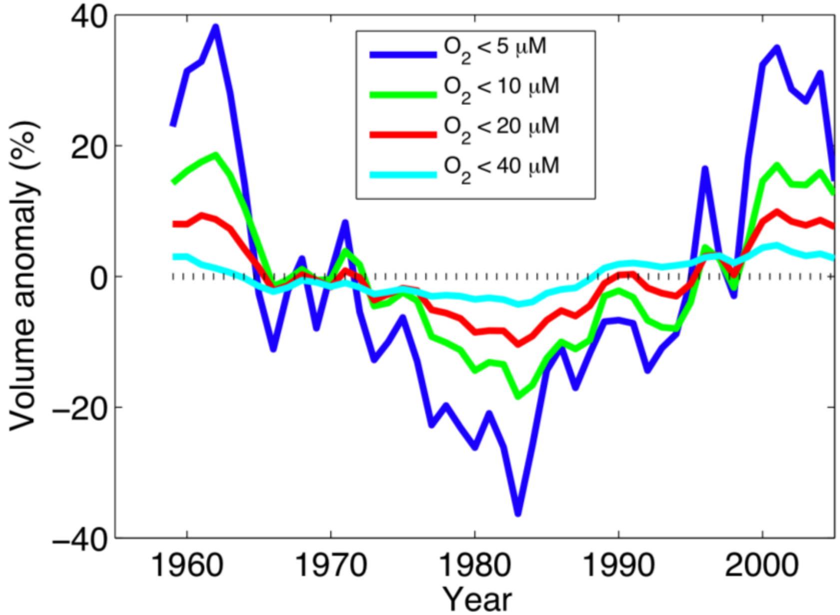




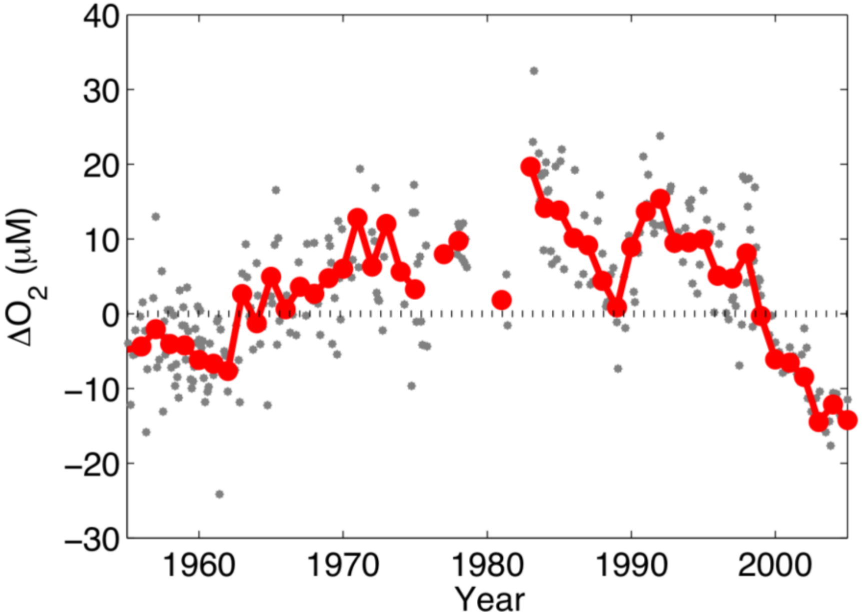
Modeled variation in pH along a transect off central California (near Monterey). A trend in pH due to rising atmospheric CO2 is evident. The variance in pH, a measure of the minimum tolerance range of organisms, is relatively small compared to expected/observed trends.

Hypoxic variability

Modeled volume of hypoxic water in Pacific.



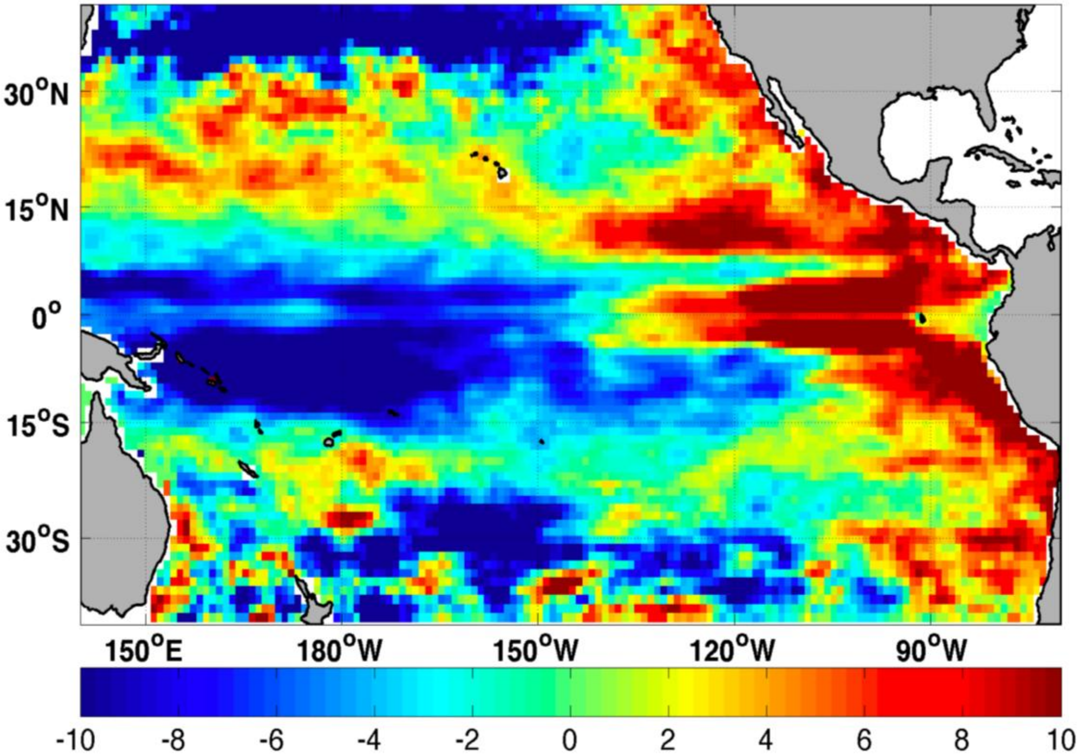
Observed oxygen anomaly at CalCOFI (300m).

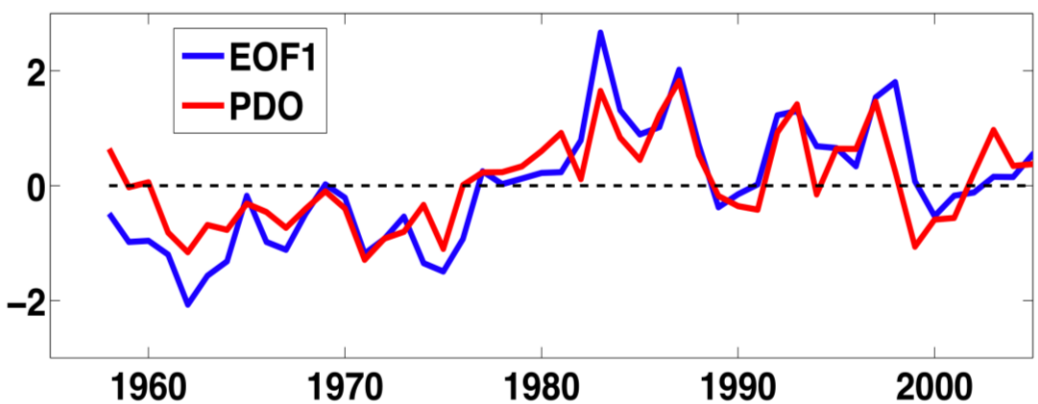


Deutsch et al. [in press]

Model simulated volume of low O_2 zones is highly variable and consistent with observations off California. Marine habitat expands and contracts accordingly, with growing amplitude as O_2 threshold decreases. The natural variations are at least as large as the long-term trends predicted in global models. Pan-Pacific variation implies a common large-scale, low-frequency forcing.

Climate Forcing





The dominant synchronous mode of Pacific isotherm depth variations involves shoaling and plunging of thermocline throughout the Eastern Pacific.

It is highly correlated to the Pacific Decadal Oscillation (PDO).

The PDO explains 25% of the variance in suboxic volume (P<0.01).